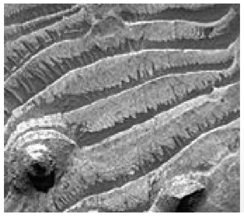
MEPAG
E2E-iSAG

Proposed Mars Sample Return (MSR) E2E-iSAG: Phase I Analysis

Scott McLennan, Mark Sephton, and the E2E-iSAG team

AGU Town Hall, Dec. 15, 2010

Pre-decisional: for discussion purposes only



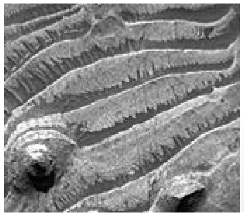
NOTE TO READERS

The material in this file represents an interim report of the MEPAG E2E-iSAG committee. Feedback on any aspect from the Mars exploration community is encouraged, and would be considered as the committee prepares its final analysis.

The team has designated two points of contact to receive written feedback:

- Dr. Chris Herd, *herd@ualberta.ca*
- Dr. Angelo Pio Rossi, *an.rossi@jacobs-university.de*

Input would be most useful if received by Jan. 24, 2011, at which point the team will compile and begin processing.



Proposed MSR Objectives & Charter Tasks

PROPOSED MSR OBJECTIVES

1. Science that would be derived from the overall campaign, culminating in the study of the returned samples

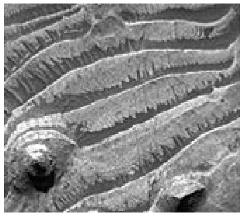
E2E FOCUS

2. Science that would be accomplished by each mission at Mars, in support of the campaign goals, by means of instruments that might be present on the individual flight elements.

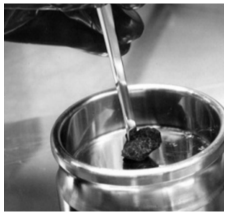
CHARTER TASKS

1. Propose reference campaign-level MSR science objectives and priorities
2. Understand derived implications of these objectives and priorities:
   a) Kinds of samples required/desired
   b) Requirements for sample acquisition and handling
   c) Draft Mars site selection criteria & reference sites
   d) *In situ* capabilities

Pre-decisional: for discussion purposes only

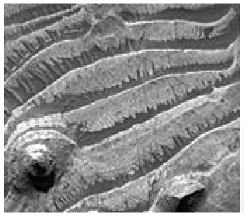


The Team

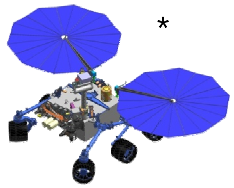


Co-Chair	Mark Sephton	Imperial College, London, UK	Organics, ExoMars
	Scott McLennan	SUNY Stony Brook, NY	Sedimentology, geochemistry Co-I MER
Science Members	Carl Allen	JSC, Houston, TX	Petrology, sample curation, Mars surface
	Abby Allwood	JPL/Caltech, Pasadena, CA	Field Astrobiology, early life, liason MAX-C
	Roberto Barbieri	Univ. Bologna, IT	Astrobiology, paleontology, evaporites
	Penny Boston	NM Inst. Mining & Tech, NM	Cave geology/biology, member PSS
	Mike Carr	USGS (ret.), CA	Mars geology, water on Mars
	Monica Grady	Open Univ. UK	Mars meteorites, isotopes, sample curation
	John Grant	Smithsonian, DC	Geophysics, landing sites, MER, MRO
	Chris Herd	Univ. Alberta, CAN	Petrology, sample curation
	Beda Hofmann	Nat. Hist. Museum, Bern, CH	Geomicrobiology, ExoMars (Deputy CLUPI)
	Penny King	Univ. New Mexico	Petrology, geochemistry, MSL
	Nicolas Mangold	Univ. Nantes, FR	Geology, spectroscopy MEX, MSL
	Gian Gabriele Ori	IRSPS, Pescara, IT	Mars geology, sedimentology, MEX, MRO
	Angelo Pio Rossi	Jacobs Univ. Bremen, DE	Planetary geology, HRSC, SHARAD
	François Raulin	Univ. Paris 12, FR	Astrobiology, extraterrestrial material, Deputy MOMA
	Steve Ruff	Arizona State Univ.	MER operations, spectral geology, MGS, MER
	Barbara Sherwood Lollar	Univ. Toronto, CAN	Astrobology, stable isotopes
	Steve Symes	Univ. Tennessee	REE, geochronology, member CAPTEM
Eng. Rep.	Peter Falkner	ESA	Advanced mission planning, MSR
	Mike Wilson	JPL/Caltech, Pasadena, CA	Advanced mission planning, MSR
Ex-officio	Dave Beaty	JPL/Caltech, Pasadena, CA	Liason to MEPAG, cat herder

Pre-decisional: for discussion purposes only



Functional Steps Required to Return a Scientifically Selected Sample to Earth



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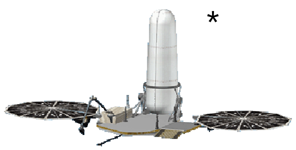
Sample Caching Rover (MAX-C & ExoMars)



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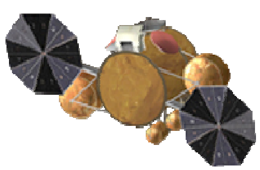
Mars Sample Return Lander



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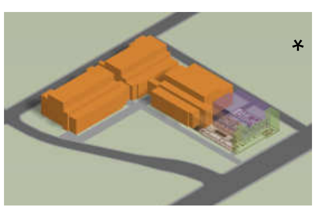
Mars Sample Return Orbiter



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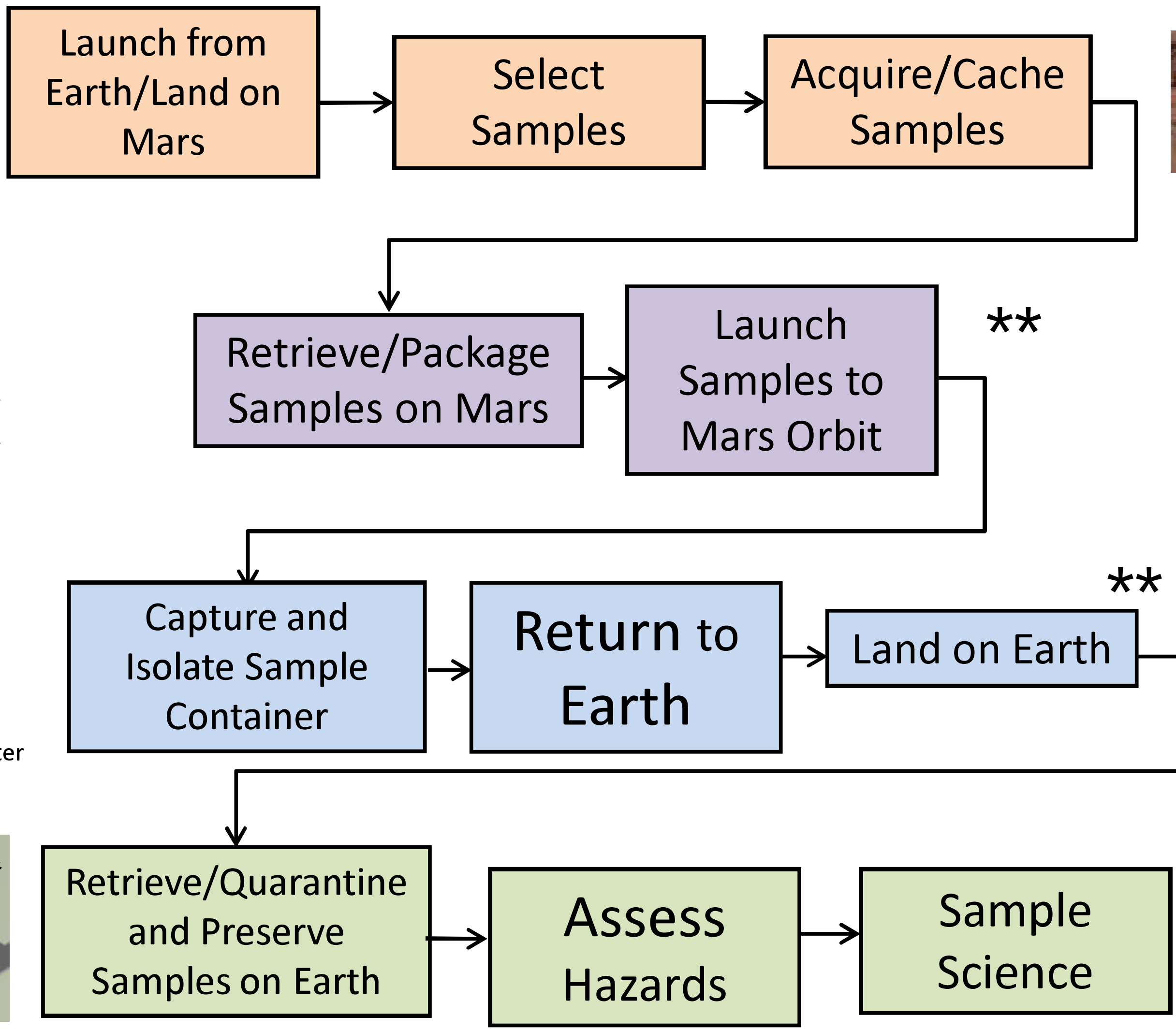
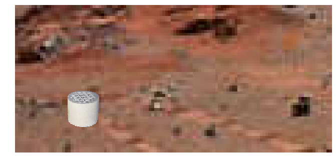
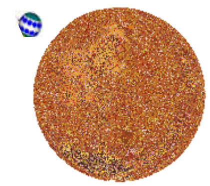
Mars Returned Sample Handling (MRSH) Facility





Sample Canister On Mars Surface *



Orbiting Sample (OS) in Mars Orbit *

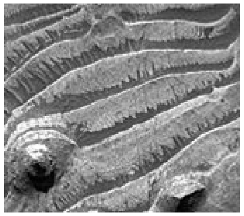
Orbiting Sample (OS) On Earth

Sample Science

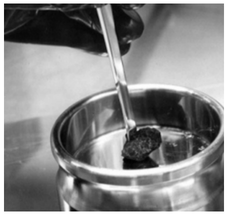
** Launching orders of MSR orbiter and lander could be reversed

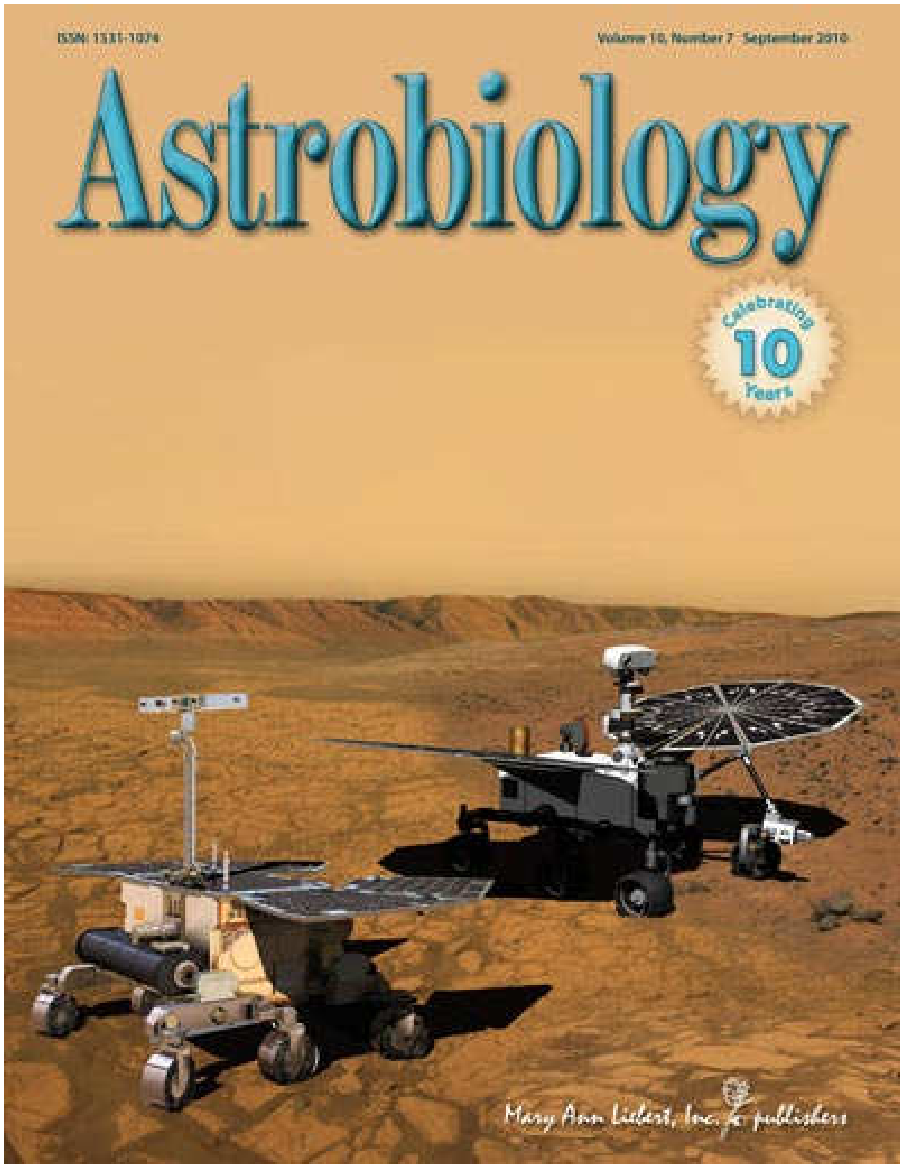
*Artist's Rendering

Pre-decisional: for discussion purposes only



Potential Mars 2018 Mission





P54A. Mars Surface and Mineralogy

Friday PM

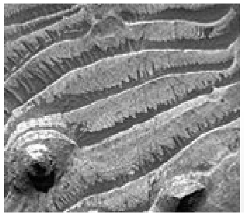
Talk (First in session): P54A-01

Grant et al.: Potential scientific objectives for a 2018 2-rover mission to Mars

Artist's concept of two rovers at the same site, based on engineering analysis as of May, 2010.

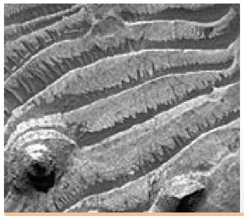
*Artist's Rendering

Pre-decisional: for discussion purposes only



Draft Science Objectives, MSR Campaign

AIM / MEPAG GOAL	#	Objective
A. Life	In rocks interpreted (from orbital and in situ data) to represent one or more paleoenvironments with high potential for past habitability and biosignature preservation:	
	1	Critically assess any evidence for past life or its precursors.
	2	Evaluate the capacity of the selected palaeoenvironments to record and retain biosignatures.
	3	Place detailed constraints on those aspects of the past environments that affected their capacity to host life.
B. Surface	1	Reconstruct the history of surface and near-surface processes involving water.
	2	Assess the history and significance of surface modifying processes, including, but not limited to: impact, photochemical, volcanic, and aeolian.
	3	Constrain the magnitude, nature, timing, and origin of past planet-wide climate change.
C. Planetary evolution	1	Quantitatively constrain the age, context and processes of accretion, early differentiation and magmatic and magnetic history of Mars.
	2	Constrain the origin and evolution of the martian atmosphere, accounting for its elemental and isotopic composition with all inert species.
D. Human exploration	1	Assess potential environmental hazards to future human exploration.
	2	Evaluate potential critical resources for future human explorers.



Preliminary Conclusions

Sampling Priorities

PARTIAL LIST OF SAMPLE TYPE PRIORITIES

<u>DRAFT</u> PRIORITY ORDER (discussion invited)

- Lacustrine sedimentary rocks*
- Hydrothermal rocks*
- Igneous rocks
- Atmospheric gas
- Airfall dust
- Regolith
- Breccia

<u>NOTES:</u>

1. Additional detail on Slides # 10-19
2. It is not assumed that it would be possible to sample all of the above at any single landing site.

* * discussion on priority, Slide #22

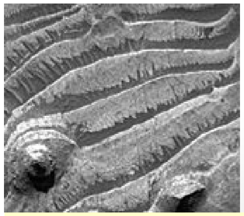
SAMPLE SUITES

a. Span the range of depositional paleoenvironments, facies and mineralogical diversity
b. As wide a range of age as possible, spanning Noachian/ Hesperian boundary

a. Span range of thermochemical environments
b. Range of rock-forming environments

a. Diversity in bulk chemical composition / mineralogy (incl. xenoliths)
b. Widest range of ages (with a focus on Noachian samples)

NO SUITE REQUIRED

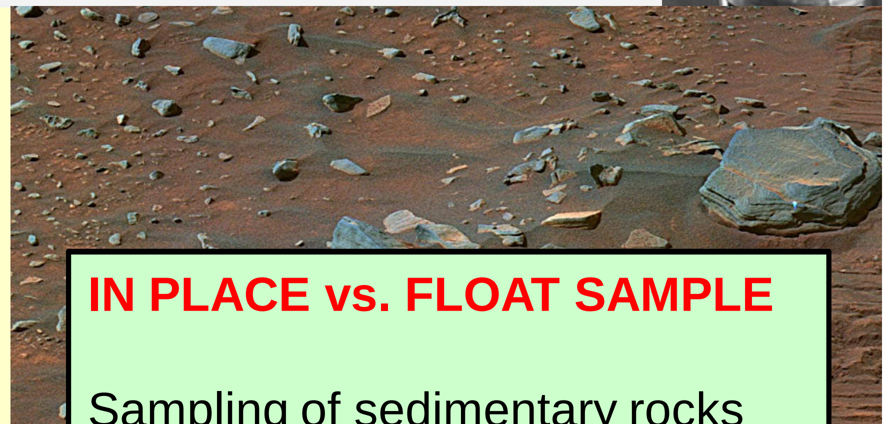


Preliminary Conclusions

Sample Acquisition Implications*

CAPABILITIES IMPLIED (priority order)

1. Outcrop or boulder sampling—rock cores (~10 g samples)
   - Ability to collect samples of opportunity (the constraints of the landing site selection process would force us into compromises).
2. Ability to collect near-surface sample regolith and dust (granular materials).
3. Encapsulation (hermeticity to be defined)
4. Atmospheric gas sampling (assume pressurized)
5. "Deep" subsurface sample from ExoMars drill (rock, soil, or both?)
6. Capability to reject previous samples, and replace with better ones.
7. Capability to record orientation

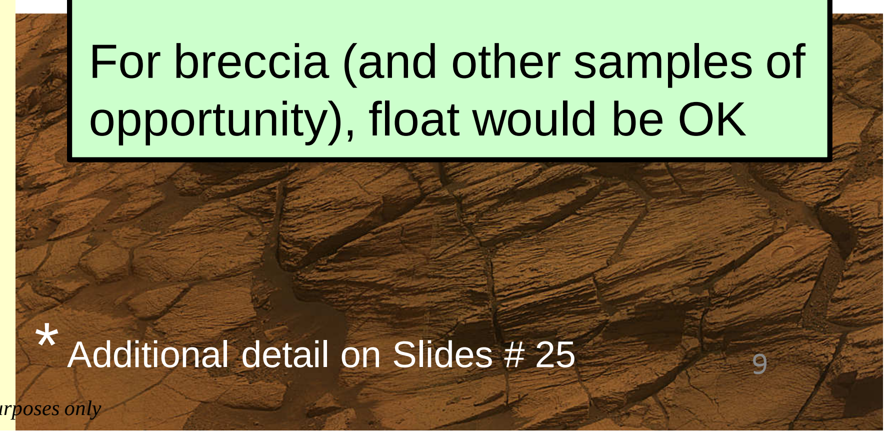


IN PLACE vs. FLOAT SAMPLE

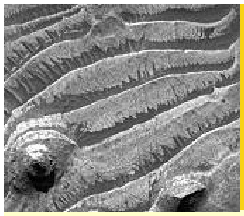
Sampling of sedimentary rocks in-place judged to be essential

For igneous rocks, in-place sampling is judged to be essential or important depending on the objective

For breccia (and other samples of opportunity), float would be OK



* Additional detail on Slides # 25



Proposed MSR Science Objectives: Life

A1. Critically assess any evidence for past life or its precursors in rocks interpreted (from orbital and in situ data) to represent one or more paleoenvironments with high potential for past habitability and biosignature preservation.

Sample types of Interest

(Given current knowledge, the following two categories of samples are of the highest priority)

A. Lacustrine sedimentary rocks, preferably including chemical sediments.
B. Hydrothermal sediments / alteration zones.

ADDITIONAL CRITERIA:

- More lateral and/or stratigraphic traceability is better
- Noachian age is strongly preferable
- Preferably from settings with evidence of biological redox opportunities, nutrient supplies, etc

Sample Suite Required? How Defined?

Suites to target highest habitability and preservation potential

For Type A: Suite to span range of facies & microfacies.

For Type B: Suite to span range of physico-chemical conditions (T, chemistry, other) of hydrothermal environment.

Importance of In-place sampling

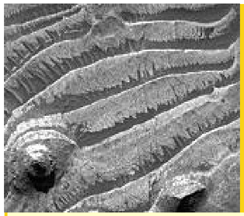
Essential

Some implications for the sampling system

1. Control of contamination by terrestrial organics is essential
2. Flexibility to orient drill relative to bedding as needed valuable
3. Either access subsurface with ExoMars drill OR exploit natural exposures to access less-altered material.

Geological Terrane Implied

Well-exposed rocks formed in one of the environments above, Noachian age. For Type A, significant stratigraphic (and lateral) section essential.



Proposed MSR Science Objectives: Life

A2. Evaluate the capacity of the selected palaeoenvironments to record and retain biosignatures, in a similar set of samples to objective A1.

Sample Types of Interest

As per A1, plus:

- surface & subsurface sample pair to evaluate potential effects on organic preservation with depth

Sample Suite Required? How Defined?

Yes. Suites TBD *in situ*. Similar to A1, with additional considerations, e.g.:

- spanning alteration gradients (modern, ancient) that may affect preservation;
- array of mineralization facies

Importance of In-place sampling

Essential

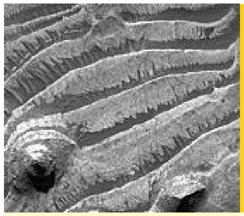
Some implications for the sampling system

As per A1, plus need to:

- either access subsurface with ExoMars drill OR exploit natural exposures to access less-altered material.
- Be able to drill harder rocks (with higher preservation potential)

Geological Terrane Implied

As per A1



Proposed MSR Science Objectives: Life

A3. Place detailed constraints on those aspects of the past environments that affected their capacity to host life, in a similar set of samples to objective A1.

Sample Types of Interest

As per A1, plus:

- High priority on chemical sediments for contained evidence of paleoenvironmental conditions

Sample Suite Required? How Defined?

Yes. Suites similar to A1, with additional considerations, e.g.:

- spanning range of palaeoenvironments to study changes in habitability

Importance of In-place sampling

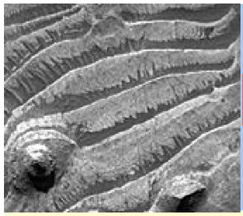
Essential

Some implications for the sampling system

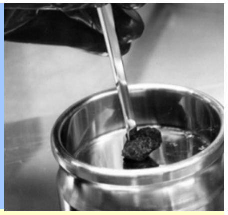
As per A1

Geological Terrane Implied

As per A1



Proposed MSR Science Objectives: Surface



B1. Reconstruct the history of surface and near-surface processes involving water.

Sample Types of Interest (Priority Order)

1. Lacustrine sediments
2. Hydrothermal deposits
3. Fluvial deposits (alluvial fans, terraces, etc.)
4. Low temperature alteration products (weathering, serpentinization, etc.)

(non-datable samples to have known stratigraphic age, or preferably known relations to datable samples

Sample Suite Required? How Defined?

1. Suite of lacustrine samples to span range of depositional environments and mineralogical diversity
2. Suite of hydrothermal samples of different thermochemical environments

Importance of In-place sampling

High

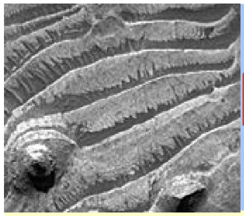
Some implications for the sampling system

Need multiple samples isolated from each other

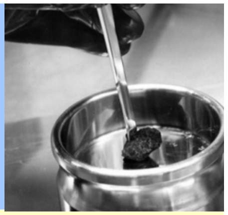
Preserve stratification/depositional structures

Geological Terrane Implied

1. Noachian/Lower Hesperian terrane for which there is evidence (mineralogy, geomorph.etc.) of standing bodies of water
2. Presence of hydrothermal indicator minerals in a plausible geologic setting for hydrothermal activity



Proposed MSR Science Objectives: Surface



B2. Assess the history and significance of non-aqueous surface modifying processes, including, but not limited to: impact, photochemical, volcanic, and aeolian.

Sample Types of Interest (Priority Order)

1. Volcanic unit with known stratigraphic age
2. Impact breccias from large Noachian crater or basin
3. Regolith
4. Eolian sediments and sedimentary rocks

Sample Suite Required? How Defined?

Neither 1 nor 2 would require a sample suite, although a suite is desirable for both

Importance of In-place sampling

Essential for volcanic unit, moderate for impact breccia

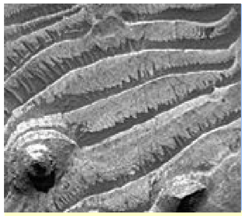
Some implications for the sampling system

Include weathering rinds

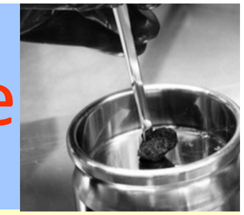
Need system (i.e., cores long enough or RAT) to get fresh samples, below weathering rinds

Geological Terrane Implied

1. Post-Noachian volcanic unit with known stratigraphic relation with crater dated units
2. Noachian terrane with access to ejecta or interior of large crater/basin



Proposed MSR Science Objectives: Surface



B3. Constrain the magnitude, nature, timing and origin of past planet-wide climate change.

Sample Types of Interest (Priority Order)

1. Suite of sedimentary rocks, both clastic and chemical, that crosses the Noachian/Hesperian boundary
2. Ancient, preferably Noachian, soils or weathering profiles

Sample Suite Required? How Defined?

1. Suite of samples of different ages to assess how sedimentary environment changed with time
2. Sample pedogenic profile and/or weathered and unweathered rocks

Importance of In-place sampling

Essential

Some implications for the sampling system

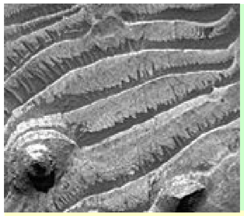
Need multiple samples isolated from each other

Need system to get fresh samples, below recent weathering rinds

Preserve stratification/depositional structures

Geological Terrane Implied

1. A sedimentary sequence that crosses Noachian/Hesperian boundary
2. Noachian terrane with range of both secondary and primary minerals



Proposed MSR Objectives: Planetary Evolution

C1. Quantitatively constrain the age, context and processes of accretion, early differentiation, and magmatic and magnetic history of Mars.

Sample Types of Interest (Priority Order)

1. Ancient igneous rocks, as unaltered and unweathered as possible, in particular:
   a. Noncumulus basalt (e.g., chilled flow margin)
   b. Xenoliths (including both mantle and crustal xenoliths)
   c. Ultramafic rocks
   d. Evolved igneous compositions
2. Young volcanic rocks

Sample Suite Required? How Defined?

Overall, a suite of igneous rocks is desired that has diversity in bulk chemical composition, probable age, and magnetic character

For type 1a,b, a suite of at least 3 oriented samples of Noachian or early Hesperian igneous outcrop

Samples of opportunity: exotic igneous blocks

Importance of In-place sampling

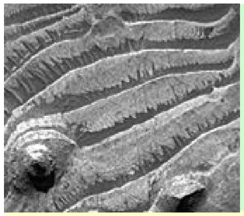
Very high

Some implications for the sampling system

For paleomag, drill, mark and preserve orientation with respect to Mars surface

Geological Terrane Implied

Noachian to early Hesperian, with outcrops of igneous rock and/or 'float' tied to proximal mapped or mappable units



Proposed MSR Objectives: Planetary Evolution

C2. Constrain the origin and evolution of the martian atmosphere, accounting for its elemental and isotopic composition with all inert species.

Sample Types of Interest (Priority Order)

1. Atmospheric sample (quantity TBD)
2. Samples with trapped atmospheric gases (e.g. impact glass)
3. Samples preserving chemical or isotopic proxies for ancient atmospheres (e.g., alteration rinds, fluid inclusions, chemical sediments)

Sample Suite Required? How Defined?

For type 1, a single sample of atmosphere
No suite required for samples type 2 and 3

Importance of In-place sampling

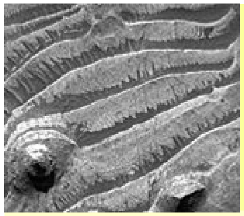
Moderate for sample types 2 and 3

Some implications for the sampling system

Should be able to pressurize ambient atmosphere, preserve trace gases

Geological Terrane Implied

Any locality is suitable for gas sample
Solid samples (types 2 and 3) would be samples of opportunity



Proposed MSR Objectives: Human Exploration

D1. Assess potential environmental hazards to future human exploration.

Sample Types of Interest (Priority Order)

1. Airfall dust
2. Surface regolith (accessible by MAX-C
3. Shallow regolith (accessible by ExoMars Drill)

Sample Suite Required? How Defined?

Single sample of each, no suite required

Importance of In-place sampling

Essential for sample types 2 and 3

Some implications for the sampling system

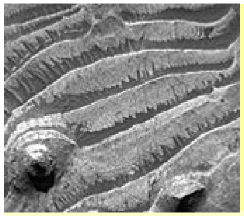
In each case, collect and preserve all size fractions

For sample type 1, recognize airfall dust in situ

For sample type 3, sample with ExoMars Drill

Geological Terrane Implied

1. Area(s) of dust accumulation
2. Within top 5 cm but 100's of m away from lander
3. Below oxidized/irradiated layer, 100's of m away from lander



Proposed MSR Objectives: Human Exploration

D2. Evaluate potential critical resources for future human explorers.

Sample Types of Interest (Priority Order)

Water or OH-bearing granular materials

Sample Suite Required? How Defined?

No suite required
Most highly hydrated sample

Importance of In-place sampling

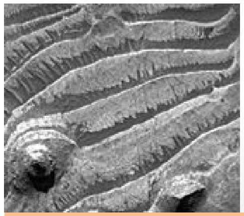
Essential

Some implications for the sampling system

Recognize and sample in situ

Geological Terrane Implied

No specific but mineralogy recognizable from orbit and in situ



Preliminary Conclusions

Sampling Priorities

PARTIAL LIST OF SAMPLE TYPE PRIORITIES

<u>DRAFT</u> PRIORITY ORDER (discussion invited)

- Lacustrine sedimentary rocks*
- Hydrothermal rocks*
- Igneous rocks
- Atmospheric gas
- Airfall dust
- Regolith
- Breccia

<u>NOTES:</u>

1. Additional detail on Slides # 10-19
2. It is not assumed that it would be possible to sample all of the above at any single landing site.

* * discussion on priority, Slide #22

SAMPLE SUITES

Lacustrine sedimentary rocks:

a. Span the range of depositional paleoenvironments, facies and mineralogical diversity
b. As wide a range of age as possible, spanning Noachian/ Hesperian boundary

Hydrothermal rocks:

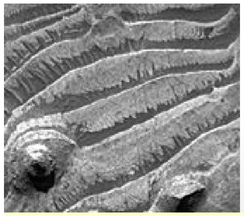
a. Span range of thermochemical environments
b. Range of rock-forming environments

Igneous rocks:

a. Diversity in bulk chemical composition / mineralogy (incl. xenoliths)
b. Widest range of ages (with a focus on Noachian samples)

Atmospheric gas, Airfall dust, Regolith:

NO SUITE REQUIRED

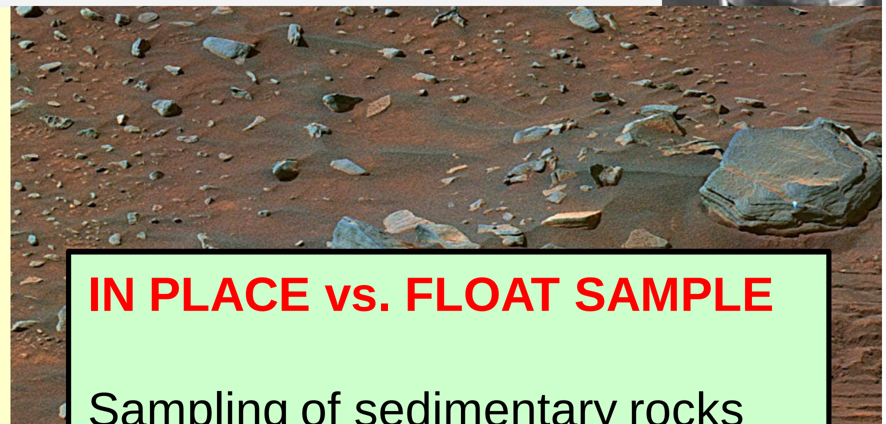


Preliminary Conclusions

Sample Acquisition Implications*

CAPABILITIES IMPLIED (priority order)

1. Outcrop or boulder sampling—rock cores (~10 g samples)
   - Ability to collect samples of opportunity (the constraints of the landing site selection process would force us into compromises).
2. Ability to collect near-surface sample regolith and dust (granular materials).
3. Encapsulation (hermeticity to be defined)
4. Atmospheric gas sampling (assume pressurized)
5. "Deep" subsurface sample from ExoMars drill (rock, soil, or both?)
6. Capability to reject previous samples, and replace with better ones.
7. Capability to record orientation

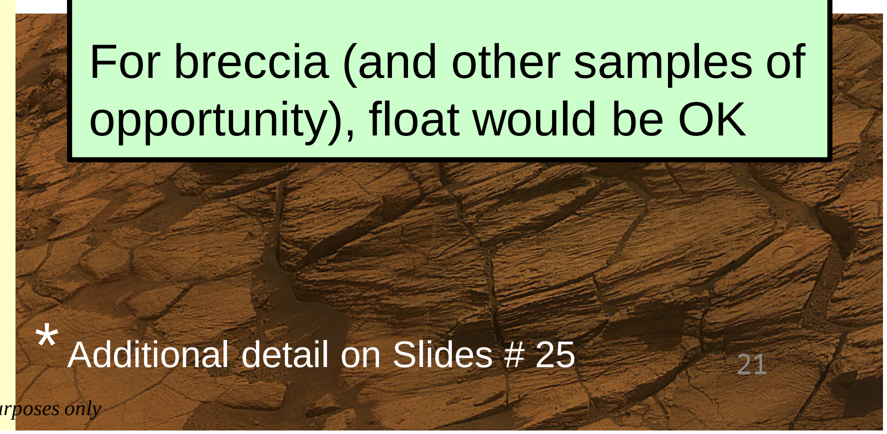


IN PLACE vs. FLOAT SAMPLE

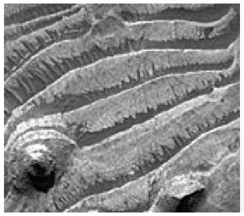
Sampling of sedimentary rocks in-place judged to be essential

For igneous rocks, in-place sampling is judged to be essential or important depending on the objective

For breccia (and other samples of opportunity), float would be OK

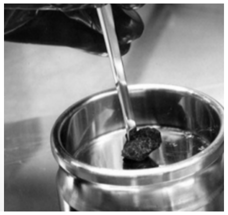


* Additional detail on Slides # 25



DISCUSSION PROMPTS

(written input welcome!)



1. Lacustrine vs. Hydrothermal: Do we need to distinguish priority at this time?

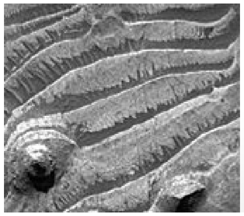
2. How important is it to return a bulk (unfractionated) sample of regolith? Why?

3. What kinds of rocks should be considered ‘samples of opportunity’, and enable specific kinds of high-value science? These would be collected if we encounter them, but might not be able to predict in advance that they are present (and formulate mission objectives around them).

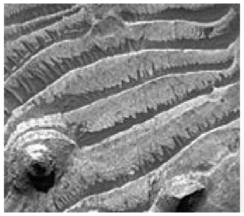
4. How important are exotic rock fragments in the regolith, and should we consider sampling strategies that concentrate them?

5. How important is it to return a subsurface sample from ExoMars?

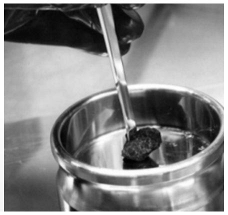
6. How important is paleomagnetism of returned samples?



BACKUP SLIDES



THIS STUDY

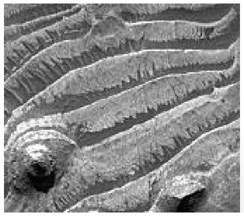


1. This analysis specifically builds from prior reports of the NRC (e.g., *An Astrobiology Strategy for the Exploration of Mars*) and the analyses by MEPAG Science Analysis Groups: ND-SAG (2008), MRR-SAG (2009), and 2R-iSAG (2010).

2. In conducting this analysis, the committee relied on its own collective experience, discussions with multiple professional colleagues, and input from several external experts (most notably in the areas of gas geochemistry and paleomagnetism).

3. The study assumes that the MSR campaign would consist of several flight elements (as described in presentations to MEPAG and the Planetary Decadal Survey), each of which must have a "controlled appetite" in areas such as mission instrumentation and sample preservation.

4. Neither NASA nor ESA has announced plans to proceed with MSR, and in NASA's case it is specifically waiting for recommendations regarding mission priorities from the NRC's Decadal Survey process (results expected March, 2011). This study does not pre-judge the outcome of that process.



Implications for Sampling System

Sampling system capability	**A1**	**A2**	**A3**	**B1**	**B2**	**B3**	**C1**	**C2**	**D1**	**D2**
Acquire multiple samples isolated, labeled in cache	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Verify that the expected samples have been collected	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Preserve stratification & depositional structures	✓	✓	✓	✓	✓	✓				
Acquire cores oriented as desired relative to bedding/outcrop	✓	✓	✓	✓	✓	✓				
Record original orientation of core relative to outcrop	✓	✓	✓	✓	✓	✓	✓			
Acquire fresh material below weathering rind	✓	✓	✓	✓	✓	✓	✓			
Retain weathering rind on samples where desired	✓	✓	✓	✓	✓	✓				
Hermetic sealing of at least some samples	?	✓								✓
Expose fresh rock face for examination of textures/structures (~3cm dia.)	✓	✓	✓	✓	✓	✓	✓			
Prevent/control sample contamination with terrestrial organics	✓	✓	✓							
Limit organic, mineral contamination between samples	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Control contamination by materials important to science measurements	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Ability to reject old samples and replace with new ones	✓	✓	✓	✓	✓	✓	✓	✓		
Acquire samples from harder rocks (for higher preservation potential)	✓	✓	✓							
Acquire a rock sample from subsurface (depth: 10cm to 200cm)			✓							
Acquire a regolith sample. Possible sieving?					✓		✓			
Acquire a regolith sample from subsurface (>10cm, up to 200cm)									✓	
Acquire and segregate an ambient atmosphere sample								✓		✓
pressurize ambient atmosphere sample								✓		
preserve trace gases in atmosphere sample								✓		
Collect dust sample: preserve all size fractions, OH-bearing materials									✓	✓